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Role of objectively measured sedentary behaviour in physical performance, frailty and mortality among older adults: a short systematic review.

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Abstract:

Sedentary behaviour (SB) has recently emerged as an independent risk factor for different health outcomes. Older adults accumulate long time in SB. Understanding the role that SB plays on health is crucial for a successful aging. This short systematic review summarizes the current evidence related to the effects of objectively measured SB on frailty, physical performance and mortality in adults >60 years old. The literature search produced 271 records for physical performance (n=119), frailty (n=31), and mortality (n=121). Finally, only 13 articles fulfilled the inclusion criteria and were included in this review. All articles but one included in the physical performance section (n=9) showed a negative association between longer time spent in SB and physical performance. A significant association of SB with higher odds of frailty was found, however this association disappeared after adjusting for cognitive status. Lastly, two of the three included studies showed positive associations between SB and mortality, but this effect decreased or even disappeared in the more adjusted models. In conclusion, there is consistency that SB is negatively associated with physical performance. However, the relationship between objectively measured SB and frailty incidence and mortality rates remains unclear and deserves further research. The use of homogenous criteria to assess SB and the inclusion of more robust research designs will help clarifying the independent effects that SB could have on physical performance, frailty, and mortality. This will ultimately help designing more efficient and comprehensive physical activity guidelines for older adults.

Keywords: sedentary lifestyle, accelerometer, physical function, frailty, mortality rates, elderly.

Introduction

Successful aging is a big concern in western societies. Globally, the older adult population has dramatically increased worldwide in the last two decades, and it is estimated that by 2015 the older population will approximately represent 22% of the world's population (Scully, 2012).

This situation provides a challenge for health and social care resources, in order to reduce the risk of non-communicable diseases and disability. In that regard, sarcopenia (i.e. loss of muscle mass and strength) plays a central role, inducing to a reduced physical performance and impaired ability to perform activities of daily living therefore increasing the risk of being frail (Roubenoff, 2000).

Frailty, a common condition among the older population (Landi et al., 2010), has been described as a biological status in which resistance to stressors is reduced mainly due to cumulative declines in the function of different biological systems (Fried et al., 2001), including the immune, endocrine, musculoskeletal and nervous system (Walston et al., 2006). Frailty leads to a state of high vulnerability to adverse health outcomes in the individuals and it is associated with worsening of physical functioning, falls, higher rates of admissions to hospital, co-morbidity, and mortality (Landi et al., 2010).

There is substantial evidence indicating that maintenance of an active lifestyle is central to successful aging. Consequently, the relationship between physical activity (PA), especially moderate-to-vigorous physical activity (MVPA), and frailty is now well established. In a recent study, Blodgett, Theou, Kirkland, Andreou, and Rockwood (2015) demonstrated a relationship between MVPA and frailty among a group of people over 50 years old. Peterson et al. (2009) concluded that physical activity is a preventive factor for frailty among the older population. A recent meta-analysis conducted by Chang and Lin (2015) suggested that older adults with frailty have the highest risks of mortality when compared with robust elderly, followed by individuals in the pre-frail phase.

While greater attention has been placed on promoting MVPA for general health, the negative effects of sedentary behaviour (SB), including those behaviours characterized by very low energy expenditure while in a sitting or reclining posture, have been shown to be highly important. In a study published by Stamatakis and Hamer (2011), SB emerged as an independent risk factor for different health outcomes such as cardiovascular and chronic diseases. In addition, large epidemiological studies have indicated that self-reported SB is associated with all causes of mortality in a dose-response manner (Katzmarzyk, Church, Craig, & Bouchard, 2009) and with the incidence of cardiovascular diseases among the general

population (Manson et al., 2002). Sedentary behaviour is highly prevalent among the older population (Davis et al., 2011; Matthews et al., 2008). Hallal et al. (2012) conducted a global assessment in more than 60 countries and found that the elderly had the highest prevalence of self-reported sitting time as compared with younger adults. The scarce number of studies conducted among older adults indicate that SB is an independent risk factor for important aging outcomes including declining physical function (Santos et al., 2012; Seguin et al., 2012), greater disability in activities of daily living (Dunlop et al., 2015), and increased mortality (Leon-Munoz et al., 2013). Finally, some reviews have systematically analysed the detrimental effects of sedentary lifestyle on a variety of health outcomes in older people (de Rezende, Rey-Lopez, Matsudo, & do Carmo Luiz, 2014; Wirth et al., 2016), but none have done so considering only objectively measured data of SB and relating it to physical performance, frailty and mortality. Identifying the health outcomes of objectively-assessed SB in the older population seems to be crucial for a successful aging.

Therefore, the aim of this short systematic review is to provide a brief summary of the published literature related to the potential role of objectively assessed sedentary behaviour with regards to some of the important outcomes of aging. Thus, this review is divided into three different sections, summarizing separately the existing evidence in regards to the potential role of objectively assessed sedentary behaviour for frailty, disability, and mortality among older adults. For each section, the limited available evidence is critically reviewed, while gaps in the current knowledge and future directions for research are identified.

Methods

The current short systematic review follows the PRISMA recommendations for reporting systematic reviews (Hutton et al., 2015).

Literature Search

Literature search was conducted (October 2016) in PubMed and Web of Science (WoS) online databases. The following Medical Subject Headings (MeSH) of the United States National Library of Medicine (NLM) and search terms with the correspondent operators were included in this Boolean search syntax: (elderly OR “older adults” OR old people” OR “elders”) AND (sedentarism OR sedentary OR sitting) AND (accelerometer OR accelerometry OR “objectively measured sedentary” OR “objectively measured physical”) AND:

- (“physical function” OR “physical performance” OR “walking performance” OR “walking velocity” OR “gait speed” OR “activity of daily living”) to identify the section of articles related with physical performance;

- (frail OR frailty) to distinguish the section of articles related with frailty status;

- (mortality OR death OR “life expectancy”) to detect the section of articles related with mortality.

The search was limited to English language and full text availability of eligible articles. Additional suitable studies were included by screening the reference lists of each included study and other relevant reviews recently published.

Eligibility Criteria

For the review, studies were included if (i) they were journal articles in full, (ii) participants were humans aged ≥ 60 years old, (iii) sedentary behaviour was assessed using objective techniques, and (iv) measurement of physical performance was carried out by field or laboratory objective tests. Performance was defined as aspects of physical function (such as strength, endurance, flexibility, speed and agility) that are associated with daily life activities that are important for maintaining independence in older adults (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). In addition, frailty should be evaluated with a validated scale. Studies were excluded from the analysis if (i) they were not available in English, and (ii) the association of sedentary lifestyle evaluated with accelerometers was not examined with physical performance, frailty or mortality. In the studies with participants younger than 60 years old we only included the subsamples older than 60 years old when reported. The retrieved studies

were imported into the EndNote Web® reference management software to remove any duplicates. Firstly, titles and abstracts were screened by two independent reviewers (AM and IA). Relevant articles were then selected for a full read of the article. If no consensus was achieved between the two reviewers, a third reviewer was consulted (AGG).

Results

The literature search produced 271 records, 119 in the physical performance section, 31 in the frailty status section, and 121 in the mortality section. After the removal of duplicates, 177 articles were excluded based on title and abstract screening (59 in the physical performance section, 17 in the frailty status section, and 101 in the mortality section), and 31 were excluded based on eligibility criteria (19 in the physical performance section, 6 in the frailty status section and 6 in the mortality section) (see details in Figure 1).

After all this process, 9 full-text article remained in the in the physical performance section, 1 in the frailty status section, and 3 in the mortality section. Thus, in total 13 full-text articles were finally included in the review (a summary of the most relevant study details of these studies are included in Table 1).

Sedentary Behaviour and Physical Performance

Seven cross-sectional studies, one interventional study and one randomized clinical trial (RCT) investigated the relationship between sedentary behaviour and physical performance (Table 1). Fleig et al. (2016) showed a negative association between time spent in sedentary activities and gait speed (Beta (β): -90.13; standard error (SE): 42.03) in 53 older adults with hip fracture. Cooper, Simmons, Kuh, Brage, and Cooper (2015) conducted a study in a large cohort of 1,727 participants from the MRC National Survey of Health and Development in England, Scotland and Wales. They showed that one standard deviation score greater time spent sedentary was associated with lower grip strength (-0.588 kg; 95% CI: -1.062, -0.115), chair rise speed (-0.550 stands/min; 95% CI: -0.898, -0.201), standing balance time (-0.050 s; 95% CI: -0.076, -0.024) and Timed Up-&-Go speed (-0.021 m/s; 95% CI: -0.028, -0.013). These effect estimates remained similar after additional adjustment for other potential confounders, except for the association with chair rise speed (-0.084 stands/min; 95%CI: -0.426, 0.257) and standing balance time (-0.024 s; 95%CI: -0.050, 0.002) which were substantially attenuated, largely due to adjustment for long-term limiting illness or disability.

A total of 117 males and 195 females, aged 65-103 years, were assessed in the article of Santos et al. (2012). They found a negative association between the composite Z-score for functional fitness and the sedentary time (β : -0.002; 95% CI: -0.003, -0.001), even adjusting for MVPA and other confounders (β : -0.002; 95% CI: -0.002, -0.001). Likewise, Rosenberg et al. (2016) confirmed these findings showing that higher sedentary activity was statistically significant associated with worse physical function (Short Physical Performance Battery (SPPB), balance

task scores, 400-m walk time, chair stand time and gait speed), regardless of participation in MVPA.

Rosenberg et al. (2015) examined the effects of an 8-week behavioural intervention to reduce sedentary time among older overweight and obese older adults. An improvement in gait speed ($p = 0.01$; $d: 0.52$) but not in chair stands ($p = 0.46$; $d: 0.11$) and SPPB total score ($p = 0.37$; $d: 0.14$) was found as a result of the intervention.

Barone Gibbs et al. (2016), in a RCT, divided participants into one of two arms: Sit Less or Get Active. The Sit Less group had the aim to reduce SB by 1 hour each day. The Get Active group had a goal to reach 150 min of MVPA each week. The Sit Less group improved SPPB significantly from 11.1 ± 0.3 to 11.6 ± 0.1 points ($p < 0.05$) over 12 weeks but no changes were detected in the Get Active group. If the components of the SPPB were separated, a significant improvement in the Sit Less Group in the chair stands was shown but not in gait speed and balance test.

In contrast, Gennuso, Thraen-Borowski, Gangnon, and Colbert (2016) found no significant associations between sedentary time and physical performance (SPPB, chair stands, gait speed). However, statistical significant associations were found between breaks in sedentary time (BST) and physical performance, independently of MVPA. The former was found in men but not in women.

Similarly, Davis et al. (2014) showed that both sedentary time ($\beta: -0.111$; 95% CI: $-0.163, -0.060$) and BST ($\beta: -0.721$; 95% CI: $-0.463, -0.978$) were negative associated with lower extremity function ($p < 0.001$). But in fully adjusted models, only BST and not overall sedentary time remained significant.

Finally, the study of Sardinha, Santos, Silva, Baptista, and Owen (2015) found a significant association between BST and physical performance ($\beta: 0.154$; 95% CI: $0.027, 0.280$), even after fully adjustment of the models ($\beta: 0.180$; 95% CI: $0.052, 0.310$). Additionally, SB was a significant predictor of physical performance, independently of BST and MVPA ($p < 0.05$).

Sedentary Behaviour and Frailty Status

The only article that met the inclusion criteria for frailty showed a significant association of SB with higher odds of frailty (Odd ratio (OR): 1.010916; 95% CI: 1.00127, 1.020655), but this association disappeared when the statistical model was adjusted for cognitive function (OR: 1.025228; 95% CI: 0.999848, 1.051252). (Table 1).

Sedentary Behaviour and Mortality

Three prospective cohort studies investigated the relationship between sedentary behaviour and mortality (all-cause, cardiovascular, cancer, other causes) (Table 1).

Ensrud et al. (2014) showed that more time spent in sedentary activities was associated with greater risk of death. Individuals in the highest SB quartile had a higher all-cause mortality (Hazard ratio (HR): 1.56, 95% CI: 1.15, 2.14) than those in the lowest SB quartile (reference group) after adjusting of models for multiple confounders. Further adjustment did not attenuate this association (HR: 1.79, 95% CI: 1.19, 2.70).

Similarly, Klenk et al. (2016) found a higher mortality risk in those subjects with the longer SB times compared with their physically active counterparts (HR: 2.05, 95% CI: 1.13, 3.73). However, after adjusting for various health outcomes and biomarkers this association disappeared (HR: 1.63, 95% CI: 0.88, 3.02).

In Fox et al. (2015) individuals were classified as low, medium and high sedentary time per day. They showed no associations between sedentary time and all-cause mortality in any case, with unadjusted (low group, HR = 0.51, 95% CI: 0.21, 1.26) and after more completely adjusted models (low group, HR = 1.01, 95% CI: 0.35, 2.98).

Discussion

To the best of our knowledge, this is the first review that examines the association between objectively measured sedentary behaviour and its effects on physical performance, frailty and mortality in older people. Although the number of studies in which accelerometers were used in order to ascertain sedentary behaviour is very limited in this population, a relationship between sedentary behaviour and a worsened physical performance is observed. However, the association between sedentary behaviour and frailty incidence and mortality rates remains unclear due to the reduced number of studies available in the literature.

Effects of sedentary behaviour on physical performance

Earlier studies where sedentary lifestyle has been measured by auto-reported questionnaires show that the longer time older adults spend on SB, the higher adverse health outcomes (i.e. diabetes, cardiovascular diseases) present, independently of MVPA (Wilmot et al., 2012). Disability is a major adverse health outcome resulting in limitations in the activities of daily living. This is of special interest, since physical activity has been proposed for the prevention of impaired physical functioning in older ages (Lang, Guralnik, & Melzer, 2007). However, these studies do not consider sedentary time as an independent domain of behaviour.

In the current review, we have found a negative association between SB and physical performance, regardless of MVPA in two of the cross-sectional studies reviewed (Rosenberg et al., 2016; Santos et al., 2012). Likewise, Fleig et al. (2016) and Cooper et al. (2015) found a negative association between time spent on sedentary activities and various physical performance tests in older adults. Accordingly, Dunlop et al. (2015) found a strong relationship between greater time spent in SB and the presence of activities of daily living disability, and Ikezoe, Asakawa, Shima, Kishibuchi, and Ichihashi (2013) with a slower time in the Timed Up-&-Go test and lower muscle strength. The independent relationship of sedentary time and physical performance extends recent findings demonstrating that objectively measured sedentary time, controlled for MVPA, is related to metabolic syndrome (Bankoski et al., 2011), cancer (Lynch et al., 2011), and mortality (Koster et al., 2012). In contrast, investigations performed in adults failed to relate sitting time with impaired muscle strength or gait/mobility (Reid et al., 2016). These discrepancies may be attributable, at least in part, to the heterogeneity in the participant study samples examined.

Sedentary behaviour and physical performance have also been related longitudinally. Seguin et al. (2012) studied 62,000 women aged 50 to 79 years from the Women's Health Initiative, and observed that those with the higher auto-reported sitting time and total sedentary time at the beginning of the study, had the higher reduction in self-reported physical performance after 12.3 years' follow-up. Unfortunately, self-report is susceptible to socially desirable responding (Adams et al., 2005), and older adults have a less accurate recall (Bonney et al., 2001).

Thus, objectively assessed sedentary behaviour as well as home-based physical performance tests may provide more accurate and reliable results. According to our literature review, the RCT study performed by Barone Gibbs et al. (2016) demonstrated that a 12 week intervention aimed to reduce SB has a higher effect on physical performance rather than on time spent on MVPA in older sedentary but highly physically functional adults. In agreement, Rosenberg et al. (2015) showed that an 8-week behavioural intervention to reduce SB is feasible and effective among older overweight and obese adults in order to increase physical performance.

The present findings highlight the need to separate SB from insufficient MVPA patterns. This is important because it enables SB as a modifiable additional risk factor for impaired physical performance, disability and loss of independence. Beyond this, there seems to be a negative relationship between spending more time on sedentary activities and physical performance.

Moreover, it is important to discuss that the way sedentary time is spent also matters. For example, Sardinha et al. (2015) as well as Davis et al. (2014) found that breaking-up time in SB was positively associated with physical performance in older adults, even after controlling for overall time in MVPA and SB. Davis et al. (2014) also reported that breaking-up time in SB predicted overall physical performance and was associated to higher scores in selected fitness parameters like upper and lower body muscle strength. This is not the case of high functioning older adults who spend over an hour a day walking, where higher SB and lower breaks were associated with an improved muscle quality (Chastin, Ferriolli, Stephens, Fearon, & Greig, 2012). Given the surprising results, authors explain it by a higher body fat that might provide a training stimulus to maintain muscle power.

Gennuso et al. (2016) reported that longer bouts and fewer breaks in SB is negatively associated with physical function in older adults, regardless of participation in MVPA. This adds to previous research where the odds for abdominal obesity decreased 7% for each additional hourly break in sedentary time in older women (Judice, Silva, Santos, Baptista, & Sardinha, 2015), as well as triglycerides and plasma glucose (Healy, Dunstan, et al., 2008).

These findings represent a new challenge for public health recommendations regarding how to break up sedentary patterns complementary to those for physical activity in order to improve physical functionality.

Effects of sedentary behaviour on frailty status

Current scientific evidence consistently shows that changes in body composition, especially loss of muscle mass, together with low PA and high SB, could be an important contributor for developing frailty in older adults (Fried et al., 2001). Interestingly, regular exercise is probably the only non-drug derived therapy effective to improve physical function, cognitive performance and mood (Landi et al., 2010), besides sarcopenia (Gianoudis, Bailey, & Daly, 2015), which is the central problem in the frailty syndrome.

Despite all the potential benefits of physical activity in relation to frailty, frail older adults spend 84.9% (about 10 hours), of their daily time in sedentary behaviours (Jansen et al., 2015). Previous evidence indicates that physically inactive individuals who have higher levels of functional disability (Tremblay, Kho, Tricco, & Duggan, 2010), and those individuals who have high levels of sedentary behaviour are more likely to be frail (Peterson et al., 2009).

DA Silva Coqueiro et al. (2016) found a positive association between self-reported sedentary time and frailty in 316 community-dwelling older adults. The authors calculated that 7 hours per day of sedentary behaviour was the best cut-off point to discriminate frail individuals. However, this cut-off point is quite low in comparison with other studies reporting objectively measured SB (Jansen et al., 2015).

The only study that met the inclusion criteria in the present literature review for the frailty section was the one recently published by Bastone Ade, Ferriolli, Teixeira, Dias, and Dias (2015). This investigation found that the frail group spent more time in SB than their robust peers. Sedentary behaviour was significantly associated to frailty, even after adjusting by the number of chronic health conditions, but this association disappeared when the statistical model was adjusted by cognitive status. Bastone and coworkers did not report an association between SB and frailty status independently of the PA levels. This was the case in Blodgett et al. (2015) study, where a positive association was observed between SB and various adverse health outcomes (frailty, self-reported health, activities of daily living disability, healthcare utilization), independent of MVPA in a community dwelling older adults (>50 years) sample. As a limitation, these cross-sectional studies do not take into consideration causality. Therefore, it

is not possible to certainly know if SB causes the appearance of frailty or if frailty can cause that individuals choose to have a more sedentary lifestyle.

Longitudinal studies like the one by Song et al. (2015) support the existing idea of a relationship among daily sedentary time and the development of a frailty status, regardless of MVPA. But the scarce available data prevent to robustly demonstrate this association, and more studies using similar methodologies both to measure sedentary behaviour and frailty are needed.

Effects of sedentary behaviour on mortality

As early as in the 1950s, we can find the first indication that SB could markedly increase adverse health outcomes. Morris, Heady, Raffle, Roberts, and Parks (1953) demonstrated a double age-adjusted rate of fatal coronary heart disease in bus drivers (sedentary) when compared with conductors (active) workers.

Since then, much research efforts have been focused on the relationship of an active lifestyle and various health outcomes, even with all-cause mortality rates (Bembom, van der Laan, Haight, & Tager, 2009). However, much less attention has been devoted on the effects of SB on mortality. Again, scientific literature relies on self-reported questionnaires to demonstrate an association between SB and mortality (all-cause, cardiovascular, colorectal cancer, other causes) in adults and older adults, independently of PA levels (Dunstan et al., 2010). This implies the limitation that questionnaires may not correctly differentiate sedentary time from light physical activity (Pate, O'Neill, & Lobelo, 2008), but the existing scientific literature using objective PA measurements is very scarce at the moment (Pate et al., 2008).

While Ensrud et al. (2014) observed that individuals in the higher SB quartile had a higher all-cause mortality than those in the lower SB quartile, Fox et al. (2015) found that despite spending a mean time of 11 SB hours, the study participants did not show an association among mortality rates and sedentary time volume.

Klenk et al. (2016) found a higher mortality risk in those subjects who spent more time in sedentary activities. However, when biomarkers were included as a confounding variable the association disappeared.

Interestingly, a large recent review combining data from over one million participants found that 60-75 minutes of physical activity a day eliminated the harms of sitting when it came to

measuring death from cardiovascular disease or death by all causes (Ekelund et al., 2016). Despite the large number of people included in the review, the results should be taken with caution as they are based on self-report PA and SB data. When we take into consideration populations younger than those included in this review, studies mainly report a significant effect of SB on mortality (Healy, Wijndaele, et al., 2008; Koster et al., 2012). Among those, Koster et al. (2012) concluded that sedentary behaviour is a risk factor for mortality independent of moderate-to-vigorous physical activity. Unfortunately, drawing conclusions in this section is complicated because of the small number of studies and the confusing results of each of them.

Methodological issues

To date, the use of accelerometers is considered the most valid and reliable method to assess SB, despite not all devices are able to discriminate between sitting and standing changes in the posture (An, Kim, & Lee, 2016). In order to make stronger the conclusions of this review, only studies using accelerometers to assess SB were included. However, the variety of devices utilized and the diversity in techniques regarding data extraction and analysis across studies makes difficult drawing definitive conclusions.

Reactivity is an important point to take into account when measuring PA and SB with accelerometry because it may introduce a relevant bias. Although the Hawthorne effect has been recognized as a potential limitation of the accelerometry method, evidence remains limited (Dossegger et al., 2014). It seems clear that in children and adolescents there may be some reactivity (Kremers & Brug, 2008). However, tampering with devices seems to be less likely among older adults (Pedisic & Bauman, 2015). None of the studies included in this review use strategies to avoid reactivity, therefore the results and conclusions must be interpreted with caution since the evidence in this area is still scarce.

The number of valid days and the minimum hours per day included in the analysis from the accelerometer data is another important methodological issue when working with these type of devices. The average number of valid days to include accelerometer data in the analysis is 3.6 ± 1.4 days among the studies reporting this value included in the review. However, according to the study of Hart, Swartz, Cashin, and Strath (2011) conducted in older people, at least five days are necessary to adequately capture the SB. Thus, studies which take less than 5 valid days for the accelerometry analysis might be unrepresentative. Moreover, cut-offs points

for sedentary strip establishment is also important, knowing that they are dependent on the analyses unit (i.e. epoch length and axes) (Aguilar-Farias, Brown, & Peeters, 2014).

The third important methodological variable to consider is the criteria for non-wear time of the accelerometers. In that regard, published studies are divided between the algorithm proposed by Troiano (2007) or the algorithm recommended by Choi, Liu, Matthews, and Buchowski (2011). The latter incorporates improvements for the misclassification of time intervals spent in SB that do not pass the wear/non-wear classification criteria for the low activity counts. Thus, studies in populations with a low physical activity and high SB patterns, such as older adults, could likely benefit from these improvements (Choi et al., 2011).

Although according to the definition of sedentary behaviour (Sedentary Behaviour Research, 2012) only sedentary behaviour should be accounted during waking hours, one study in this review included the time that individuals spend sleeping as SB (Klenk et al., 2016). This can lead to an overestimation of sedentary time and should be taken into account when comparing results from studies using different approaches.

Finally, another important aspect that should be considered when studying sedentary behaviour in relation to health outcomes is MVPA. This factor should be taken into account within the covariates included in the statistical models so that the independent effect of SB can be ascertain. The same applies with health status, especially in older adults studies in order to avoid confounding interactions (Andrade & Fernandes, 2012).

Although Pedisic and Bauman (2015) concluded that accelerometer-based studies had limitations regarding generalisability, validity, comprehensiveness, simplicity, affordability, adaptability, between-study comparability and sustainability, many of these methodological aspects have not yet been homogenized. Overall, the discrepancy in the methodological aspects across the analysed studies in this review may preclude us from drawing definitive conclusions, although a recent review that could help researchers to make better decisions before and after data collection using accelerometers, in order to obtain more valid and comparable data has been published (Migueles et al., 2017). Consistency in the methodological aspects when assessing SB and stronger research designs are crucial points to confirm the observed findings in this review.

Summary and conclusion

There is consistent evidence of the relationship between objectively measured sedentary behaviour and physical performance in the elderly. The association among sedentary lifestyle, frailty incidence and mortality rates warrant further investigation. The lack of studies assessing these outcomes and the wide variety of methodological issues reported among the reviewed studies make difficult to draw definitive conclusions. Another important aspect that deserves further investigation is the manner that sedentary behaviour is accumulated. Breaks in sedentary time seem to minimize the decline of physical performance with aging. Future research should test this hypothesis also regarding frailty and mortality outcomes.

While sedentary lifestyle can have an independent relationship on the outcomes of interest for this review, future studies should consider how physical activity and sedentary behaviour could simultaneously influence these outcomes. The latter has already been studied in relation to cardio-metabolic health variables (Bakrania et al., 2016) but, to our knowledge, no studies have analysed this combined effect on physical performance, frailty and mortality.

Nonetheless, homogeneity with regards to the assessment of SB and other methodological issues commented in this review will help clarifying the potential role of SB (and patterns) on physical performance, frailty, and mortality among older adults.

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Table I. Main characteristics of the selected studies.

Study	Design	No. of participants; sex; age [years (mean \pm SD or range)]	Main characteristic of the subjects	Device used to assess SB	Parameter (and value) in which SB assessment is based on	Valid days; Hours for valid day*	Primary Outcome	Secondary Outcomes	^a Magnitude of the association	^b Magnitude of the association
Barone Gibbs et al. 2016	RCT	38; F (17), M (11); 68 \pm 7	Inactive; Community-dwelling	SenseWearPro armband	≤ 1.5 METs	≥ 4 ; ≥ 10	Physical Function	MVPA	SPPB: 0.5[‡] 400-W: 0.07 [‡] GS: -0.04 [‡]	
Davis et al. 2014	Cross-sectional	217; F (109), M (108); 78 \pm 6	General population; Community-dwelling	ActiGraph GT1M	<100 CPM	≥ 5 ; ≥ 10	Physical Performance	BST, MVPA	SPPB: β = -0.111 BT: β = -0.030 CR: β = -0.042 GS: β = -0.039	SPPB: β = -0.050 BT: β = -0.014 CR: β = -0.100 GS: β = -0.027
Fleig et al. 2016	Cross-sectional	49; F (32), M (17); 80 \pm 8	After hip fracture; Community-dwelling	ActiGraph GTX3+	<100 CPM	≥ 3 ; ≥ 8	Physical Performance	LIPA, MVPA, Steps, Quality of life, Falls self-efficacy	GS: β = -90.13	
Cooper et al. 2015	Cross-sectional	1727; F (837), M (890); 60-64	General population; Community-dwelling	Actiheart	≤ 1.5 METs	N/R; ≥ 48	Physical Performance	MVPA, PAEE	HS: β = -0.588[°] CR: β = -0.550[°] BT: β = -0.050[°] TUG: β = -0.021[°]	HS: β = -0.540[°] CR: β = -0.084 [°] BT: β = -0.024 [°] TUG: β = -0.011[°]
Gennuso et al. 2016	Cross-sectional	44; F (28), M (16); 70 \pm 8	Ability to walk unaided; Community-dwelling	activPAL	Posture (sitting/lying)	N/R; N/R	Physical Performance	BST, MVPA, Quality of life, Postural stability, Fall risk	SPPB: RC = -0.09 CR: RC = -0.21 400-W: RC = -0.01	

Rosenberg et al. 2016	Cross-sectional	307; F (222), M (85); 84 ± 6	General population; Retirement communities	ActiGraph GT3X+	<100 CPM	≥1; ≥10	Physical Performance	Mental and Cognitive Health, Physical Health	SPPB: β = -0.55 400-W: β = 20.72 BT: β = -0.15 CR: β = 1.02 GS: β = 0.23	
Rosenberg et al. 2015	Experimental	24; F (17), M (7); 71 ± 6	Overweight and obese; Community-dwelling	activPAL	Posture (sitting/lying)	N/R; N/R	Physical Performance	BST, MVPA, Steps, Quality of life, Depressive symptoms	SPPB: d = 0.14 GS: d = 0.52 CR: d = 0.11	
Santos et al. 2012	Cross-sectional	312; F (195), M (117); 74 ± 7	General population; Community-dwelling	ActiGraph GT1M	<100 CPM	≥3 (≥1w); ≥10	Physical Performance	MVPA	SFT: β = -0.002 CS: β = -0.013 AC: β = -0.010 8FUG: β = 0.015 6MWT: β = -0.301 CSR: β = -0.031 BS: β = -0.015	SFT: β = -0.002 CS: β = -0.011 AC: β = -0.010 8FUG: β = 0.016 6MWT: β = -0.100 CSR: β = -0.024 BS: β = -0.002
Sardinha et al. 2015	Cross-sectional	215; F (128), M (87); 73 ± 6	General population; Community-dwelling	ActiGraph GT1M	<100 CPM	≥3 (≥1w); ≥10	Physical Performance	BST, MVPA	SFT: β = -0.198	SFT: β = -0.165
Bastone et al. 2015	Cross-sectional	26; F (24), M (12); 66-86	Frail and nonfrail; Community-dwelling	ActiGraph GT3X	<100 CPM	N/R; ≥10	Frailty	Aerobic fitness, LIPA, MVPA, Steps	FS: OR = 1.0087	FS: OR = 1.0252
Ensrud et al. 2014	Prospective	2918; F (30), M (2918); 79 ± 5	General population;	SenseWearPro armband	≤1.5 METs	≥5; ≥90%	Mortality	LIPA, MVPA	ACM: HR = 1.78³	ACM: HR = 1.79³

			Community-dwelling							
Fox et al. 2015	Prospective	213; F (104), M (109); 70-+85	General population; Community-dwelling	ActiGraph GT1Ms	<100 CPM	≥5; ≥10	Mortality	MVPA, Steps, Trips, Physical Function	ACM: HR = 0.51 ^u	ACM: HR = 1.01 ^u
Klenk et al. 2016	Prospective	1271; F (554), M (717); 76 ± 7	General population; Community-dwelling	activPAL	Posture (sitting/lying)	N/R; 24	Mortality	Walking duration	ACM: HR = 2.05³	ACM: HR = 1.52 ³

SD: standard deviation. SB: sedentary behaviour. F: females. M: males. CPM: counts per minute. N/R: not reported. LIPA: light-intensity physical activity. MVPA: moderate-to-vigorous physical activity. FS: frailty status. OR: odd ratio. RCT: randomized clinical trial. METs: metabolic equivalents. SPPB: short physical performance battery. 400-W: 400-m walk test. GS: gait speed test. BST: breaks in sedentary time. BT: balance test. CR: chair rise test. PAEE: physical activity energy expenditure. HS: handgrip strength. TUG: timed up-&-go speed test. RC: regression coefficient. d: Cohen's d effect size. W: weekend. SFT: senior fitness test composite Z-Score. CS: chair stand test (SFT). AC: arm curl test (SFT). 8FUG: 8-foot up-&-go test (SFT). 6MWT: 6-minute walk test (SFT). CSR: chair sit-&-reach test (SFT). BS: back scratch test (SFT). ACM: all-cause mortality.

*Days and hours per valid day to include accelerometer data in the analysis.

^aMagnitude of the association between ST and specified outcome in the less adjusted models published.

^bMagnitude of the association between ST and specified outcome in the most adjusted models published.

^yChange from baseline to 12-week intervention.

^oThe magnitude of the association is equal per 1 SD difference/day.

³Comparison between reference (least sedentary) and quartile 4 (most sedentary).

^uComparison between reference (most sedentary) and tertile 3 (least sedentary).

Associations highlighted in bold are statistically significant at p<0.05.

Figure 1. Flow diagram on identification, screening, eligibility and inclusion of full-text articles.

